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Describes procedures for evaluating the operational performance of optical-mechanical sighting systems used for laying the major armament of towed and self-propelled artillery; includes effects of shock, vibration, and environmental conditions on sighting system performance.

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

AMSTE-RP-702-102
*Test Operations Procedure 3-2-709 — 14 December 1987
AD No.

FIELD ARTILLERY FIRE CONTROL SIGHTS

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1. SCOPE. This TOP prescribes procedures for evaluating the operational performance of optical-mechanical sighting systems used for laying the major armament of towed and self-propelled artillery; and the effect of shock, vibration, and environmental conditions on sighting system performance. Parameters are as follow:

a. Direct- and indirect-fire sighting systems are covered.

b. Static (shop) and dynamic (firing and road) tests are included.

c. The TOP covers simulated environmental tests but not environmental tests at climatic test sites.

d. The optical quality of the sights is not part of these tests.

*This TOP supersedes TOP 3-2-709 dated 26 February 1973.

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The combat effectiveness of field artillery depends greatly on the accuracy, repeatability, and integrity of its sighting and related weapon-laying systems and how well they are secured. The optical-mechanical types of sighting systems for towed and self-propelled artillery are used to aid the gunner in properly laying the major armament during direct- or indirect-fire missions. These systems include such items as direct- and indirect-fire telescopes, elevation quadrants, and related mounts.

The operational testing of these sighting systems consists of subjecting them to road travel vibrations and firing shocks under various test conditions. Then, at specified intervals, the systems are checked for loss of boresight, looseness of parts, misalignment, damage, malfunctioning, and similar effects.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

ITEM	REQUIREMENT
Mechanical jacks	10-ton capacity, sufficient to level weapon
Plumb line and bob	
Tube leveling bar	
Aiming posts	
Targets	For sighting
Boresight telescope	For boresighting and leveling weapon
Temperature chamber	To condition test item to temperatures ranging from -46° to +52° C

2.2 Instrumentation.

DEVICE FOR MEASURING	PERMISSIBLE ERROR OF MEASUREMENT*
Weapon tube elevation	0.4 mil
Counter elevation reading	
Tube azimuth	20 arc seconds
Temperature	1° C
Temperature inside climatic chamber	2% of reading
Projectile velocity	0.1%

3. REQUIRED TEST CONDITIONS.

a. Before the test is conducted, inspect and service the test facility (i.e., the towed or self-propelled weapon designated to support the test materiel) in accordance with established procedures. Ordinarily, the tactical weapon, for which the fire control equipment is intended, serves as the test facility. The original mounting of the sights to the test facility should be performed by qualified personnel.

*The permissible error or measurement for instrumentation is the two-sigma value for normal distribution. Thus, the stated errors should not be exceeded in more than one measurement of 20.

b. Particular attention should be given to the cleanliness of all mounting surfaces.

c. The sighting systems covered by this test procedure normally consist of the following components:

(1) Panoramic telescope and mount (indirect fire)
(2) Direct fire telescope and mount (direct fire)
(3) Elevation quadrant
(4) Cant corrector
(5) Alignment device

d. The following information should be recorded before conducting the actual tests:

(1) Evidence of damage to any component during transit
(2) Condition of exterior surfaces of optics, mating parts, etc.
(3) Misalignment of components
(4) Any interference between the various components when the weapon is laid at specified elevations, traverse, and vehicle cant
(5) Ease of mounting sights
(6) Positive security of sights in their respective mounts
(7) Adequacy of protective covers and sight storage facilities

e. When possible, conduct the extreme temperature tests in conjunction with testing the major armament. Perform firing tests at temperature levels of 52° C (125° F) and -46° C (-50° F). Before these tests, it is essential that all weapon components be properly inspected, serviced, and for the cold phase, winterized.

3.1 <u>Leveling the Weapon</u> (see Fig. 1 and 2). The vehicle or carriage is leveled by the three-point suspension method as follows:

a. Place the vehicle (carriage) on a hard, relatively level surface.

b. For self-propelled weapons, place three mechanical jacks beneath the vehicle in accordance with the procedures in appropriate technical manuals. Adjust the jacks to take the full weight of the vehicle. For towed weapons, spread the trails and place one jack each beneath the undercarriage, left and right. Remove all weight from the wheels of the weapon. Place a weight, such as a gun tube, across the trails to prevent any accidental movement during testing.

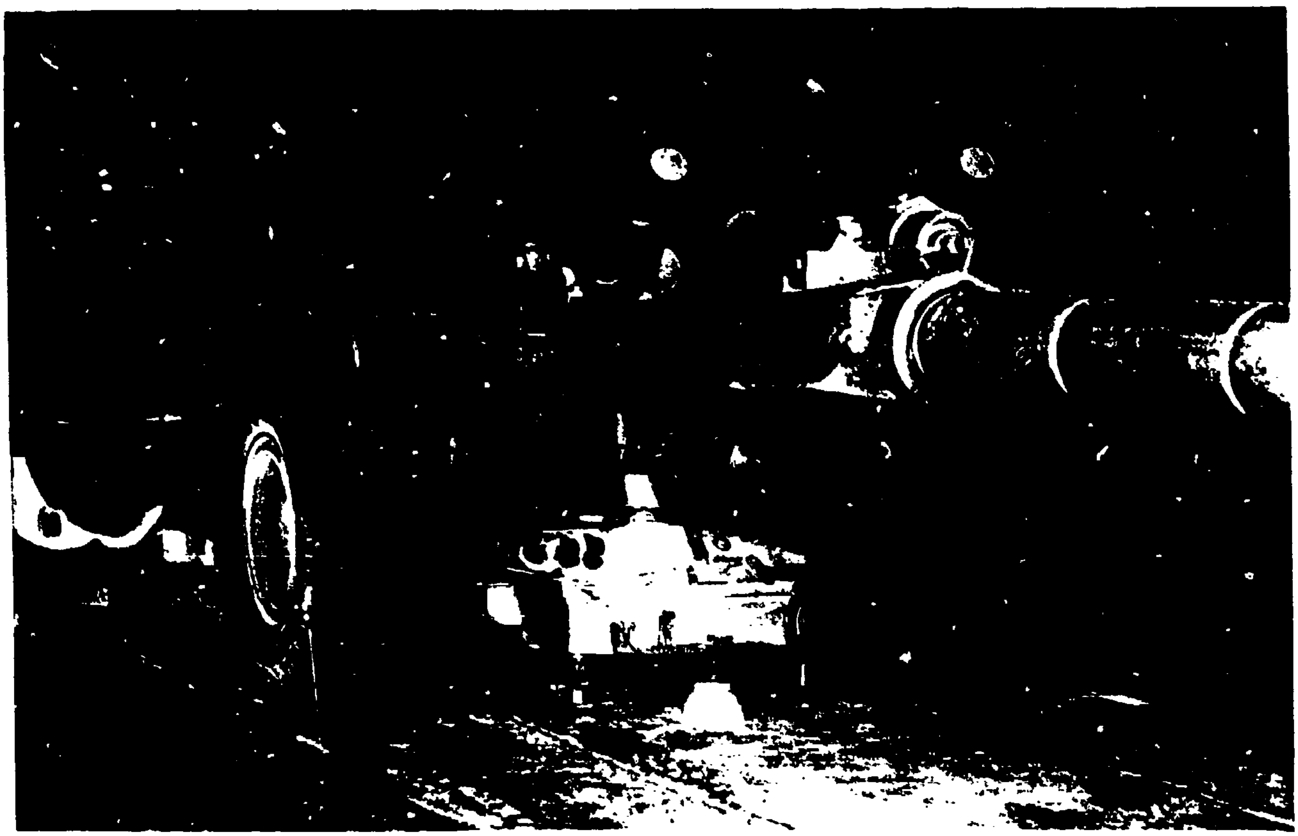
c. Place the muzzle crosshairs on the witness marks of the gun.

d. Suspend a 0.16-cm-diameter (1/16-in.) plumb line no more than 2.5 cm from the muzzle. (There should be no wind, but the plumb bob should nevertheless be immersed in oil as a precaution to dampen vibrations.)

e. Lay the gun to 0° elevation, and center the boresight telescope in the breech.

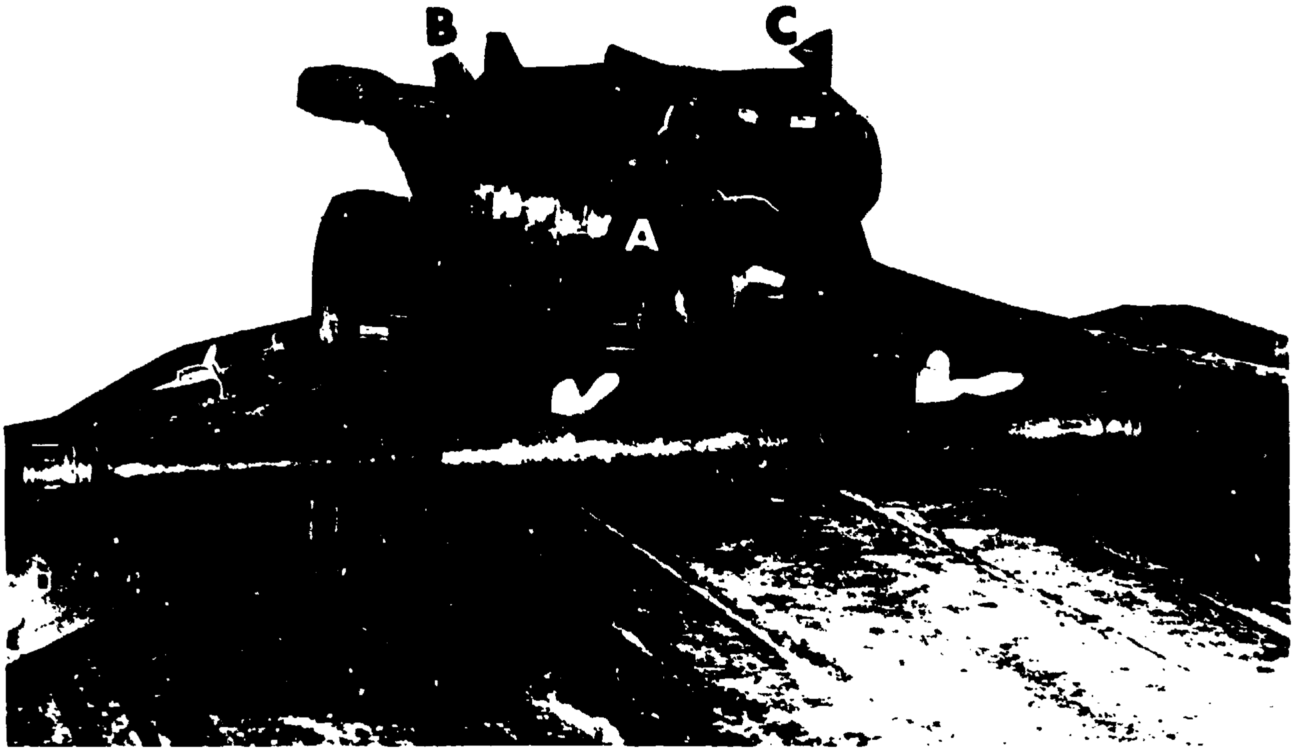
f. While sighting through the boresight telescope, traverse the weapon until the center of the telescope reticle is aligned with the vertical plumb line.

g. While sighting through the breech boresight telescope, and using the center of the muzzle crosshairs as a reference, track the plumb line through at least 50° elevation. Make appropriate adjustments to the leveling jacks to render the trunnion axis horizontal (zero cant).



M198 towed howitzer leveled by the 3-point suspension method. Howitzer is shown placed on jacks (note arrows).

Figure 1. Equipment for leveling the vehicle.



M198 towed howitzer leveled by the 3-point suspension method (rear view). A gun tube is placed across the trails for stability. Visible are the breech boresight (A), the M171 telescope (B), and the M139 alignment device (C).

Figure 2. Equipment for leveling the vehicle.

3.2 <u>Boresight Retention and Checking Target</u>.

a. A typical boresighting target is shown in Figure 3. The material used for its construction should be nonwarping and nonshrinking.

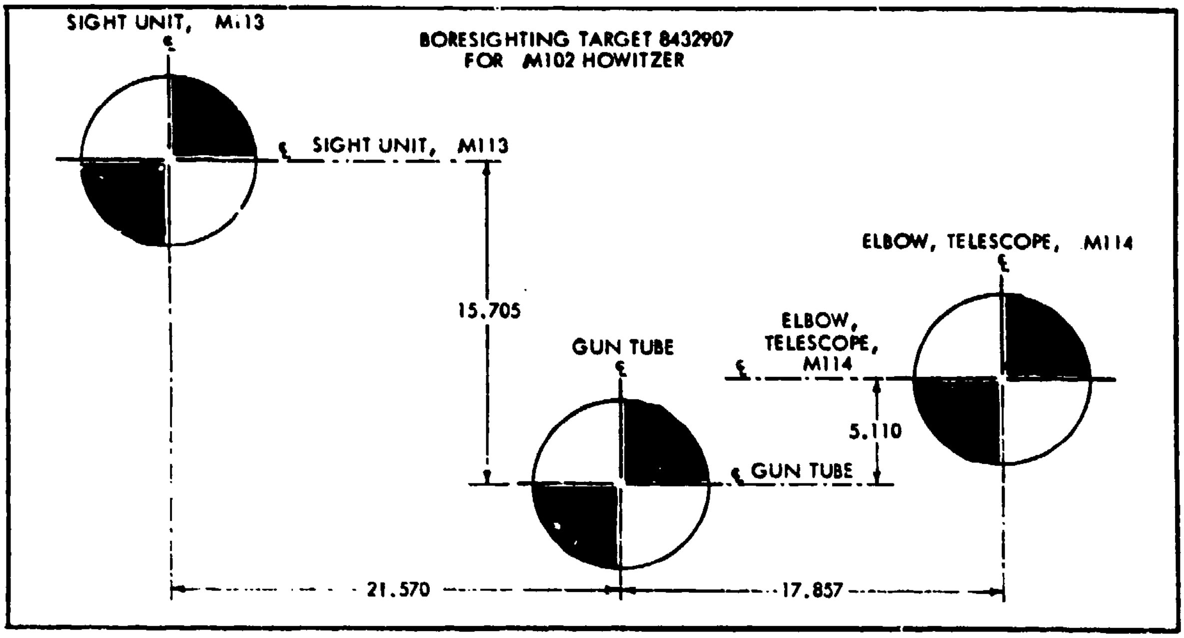


Figure 3. Boresighting target.

b. A recommended boresighting procedure is as follows:

(1) Level the trunnions (as level as possible, depending on the situation). If feasible, this should be done by tracking a plumb line from maximum elevation to maximum depression.

(2) Level the tube lengthwise by performing an end-for-end test with a gunner's quadrant.

(3) Center all bubbles (without moving the weapon tube).

(4) Adjust all indices, scales, counters, and dials to the proper reading for the weapon tube attitude; for most indicators, this will be zero. An exception is the 6,400-mil azimuth counter which should read exactly 3,200 mils.

(5) Adjust the plane of the boresighting target so that it is normal (perpendicular) to the longitudinal axis of the gun tube. Adjust the height of the gun tube target to align it with the gun boresighting system. Level the boresighting target parallel to the gun trunnions. This distance from muzzle to target should be within the range specified in the technical or maintenance manual for the weapon. The intersection of the target reference lines shall be within ±0.3 cm (0.125 in.) of the centerline of the gun tube (boresight line).

NOTE: Correct all elevations measured with a calibrated gunner's quadrant placed on the breech ring for tube droop.

(6) Finally, adjust the direct- and indirect-fire telescopes so that their reticle intersections coincide with the corresponding reference circles (aiming points) on the boresight target (Fig. 3). After this adjustment, reset the azimuth counter to 3,200 mils.

Theoretically, when all the above operations have been accomplished, the lines of sight of both telescopes are parallel to the tube centerline.

3.3 Boresighting Using Alignment Device.

a. Remove alignment device from its carrying case. Remove cover from dovetail bracket of howitzer. Wipe all machine surfaces from interface of dovetail bracket and alignment device to remove any foreign matter. Install alignment device. Sight through the telescope being tested. The boresight cross of the telescope should be aligned with the alignment device. NOTE: For the M198 howitzer, the panoramic telescope counter should read 4800 mils ±0.25, while on all other weapons, the telescope counter should read 3200 mils ±0.25.

b. If alignment is not obtained during the operation described in para a above, manipulate the adjustment screws in accordance with appropriate technical manuals (TM) to lay the reticle with the alignment device. To ensure the alignment device is serviceable, refer to the appropriate TM for serviceability check.

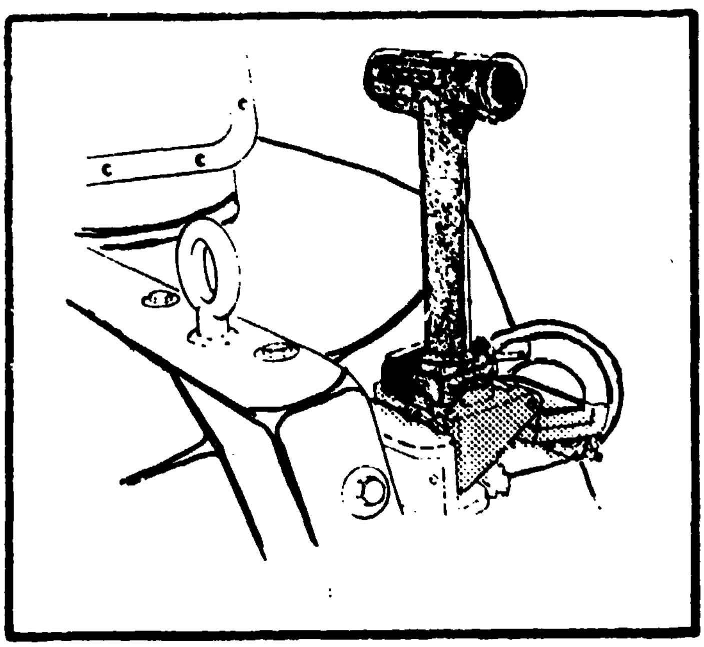


Figure 4. Boresighting using alignment device.

3.4 Boresighting on Distant Aiming Point. An alternate method of boresighting a weapon is by means of a distant aiming point (Fig. 5). The farther the aiming point is from the gun muzzle, the more accurate will be the results; thus, a celestial object, such as a star, would be an ideal point. For practical purposes, however, the aiming point is considered satisfactory if it is at least 2000 m from the muzzle.

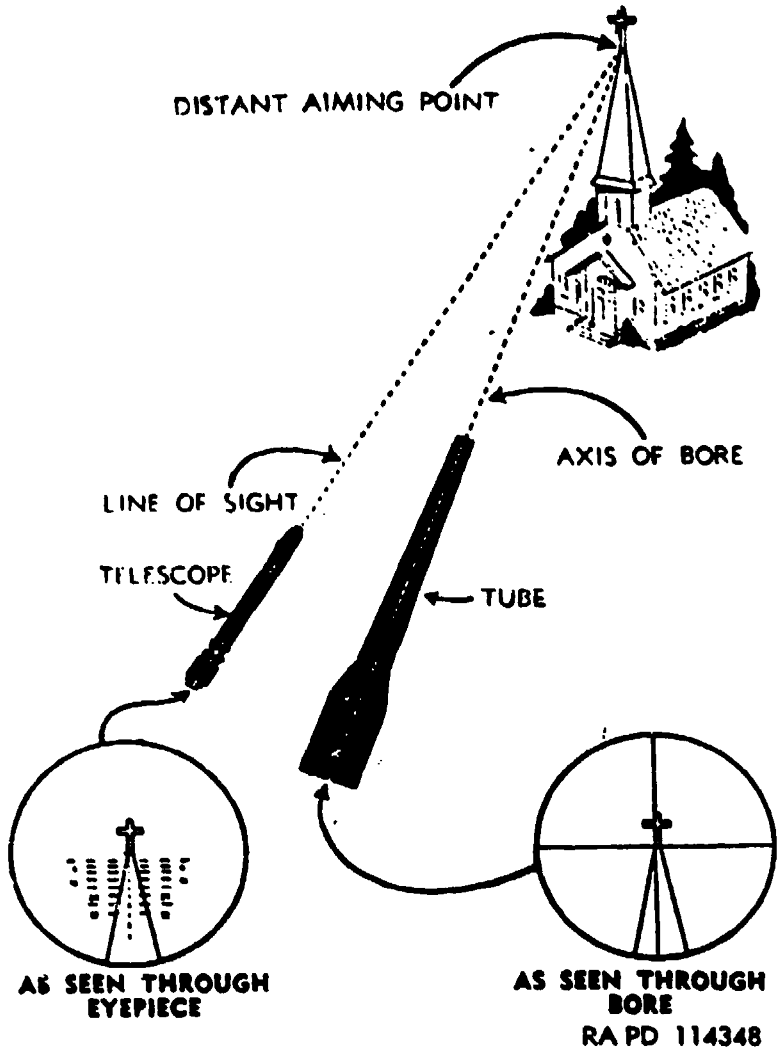


Figure 5. Boresighting on distant aiming point.

3.5 Preliminary Activities. The procedures governed by the following TOP's and the referenced paragraph are performed as prerequisites to conducting the test phases.

TITLE	TOP NO.
a. Initial Inspection	3-2-800[1*]
b. Physical Characteristics	1-2-504[2]

*Footnote numbers correspond to reference numbers in Appendix E.

4. TEST PROCEDURES.

4.1 Shop Tests.

4.1.1 Objective. To check all components of the on-carriage fire control systems for boresight error, synchronization, backlash, security, illumination, noninterference with other parts, and ease of operation. Shop tests are performed following the proper mounting of the sighting components before the dynamic testing phases and are repeated at specified intervals to determine whether the systems have satisfactorily withstood exposure to the various test environments.

4.1.2 Standards. MIL-F-13926, MIL-F-14252, (see App. E)

4.1.3 Method.

a. Boresight Retention. At the completion of each test phase (i.e., direct-fire, road, and indirect-fire tests), level the vehicle (carriage) as specified in paragraph 3.1. Align the muzzle crosshairs with the tube centerline points on the target. Then, by sighting through the direct and indirect (panoramic) telescopes, in turn, determine the amount (in mils) of shift in lines of sight (right or left, up or down) from their respective target aiming points.

NOTE: Check telescope backlash by taking the difference in the readings of the azimuth or elevation scale when the line of sight of the telescope is brought onto a fixed mark first from one direction and then from an opposite direction. This backlash will be accounted for in determining the boresight retention error.

b. Alignment of Panoramic Telescope (walk-off). With the panoramic (indirect) telescope mount properly cross-leveled, and the azimuth assembly positioned so that the optical centerline of the telescope lies on the target aiming point, elevate the tube from zero to maximum elevation while tracking a vertical plumb line, as explained in paragraph 3.1g. Re-level the telescope mount and determine the amount (in mils) that the vertical reticle line has moved from its original target aiming point. Then realign the sight and repeat the procedure while depressing the tube from maximum to zero elevation. This deflection shift, either right or left, is called "walkoff". Again, make sure that all backlash is removed.

c. Synchronization Checks. With the elevation quadrant counters reading 0°, place the calibrated gunner's quadrant on the breech ring elevation pads and measure the breech ring (gun) elevation. Repeat this procedure for elevation quadrant counter settings for each 200 mils' elevation (approximately). Then repeat the procedure while depressing the tube to each of the lower quadrant readings. Correct all breech ring elevation readings for tube droop (i.e., difference between muzzle and breech elevations). The difference, in mils, between the corrected breech ring elevation and the elevation quadrant counter readings is the synchronization (elevation) error of the elevation quadrant. (Backlash error is removed by setting the weapon and elevation quadrant, at each specified elevation, always from the same direction.)

d. Backlash.

(1) The elevation quadrant backlash is the difference in counter readings of the elevation quadrant when the tube is elevated and then depressed to each specific elevation, as measured with a calibrated gunner's quadrant placed on its appropriated elevation leveling plate on the elevation quadrant housing.

(2) The backlash of deflection adjustment knobs (indirect or direct-fire telescope mounts) can be determined by first moving the vertical reticle lines of the scope from right to left, then from left to right, onto any target reference point. The difference in azimuth readings is deflection backlash. Elevation knob backlash is determined by moving the horizontal reticle lines onto a target aiming point from the "down-to-up" then from the "up-to-down" direction. The difference in elevation scale readings of the respective telescope mounts is the elevation adjustment knob backlash.

e. Horizontal Deflection of Panoramic Telescope (Shake). "Shake" is determined as follows: Apply a gradual steady pull (per applicable MIL-SPEC or test directive) to the eyepiece of the panoramic (indirect-fire) telescope, and gradually release the pressure. While sighting through the telescope, lay the vertical crosshair on the center of a target aiming point. Again, in a similar manner, apply the specified pull to the eyepiece, but in the opposite direction, and gradually release. The horizontal displacement of the vertical crosshair relative to the target aiming point is called the "shake" of the panoramic (indirect-fire) telescope.

f. Knob Efforts. Record the torques of all adjustment knobs in clockwise and counterclockwise directions, by using standard torque wrenches and adapter plates. These torques are usually expressed in inch-ounces.

4.1.4 <u>Data Required</u>. Record the following minimum data:

a. Boresight retention error (mils)
b. Alignment of panoramic telescope (mils)
c. Synchronization readings (mils)
d. Backlash (mils) of all control knobs
e. Horizontal deflection of panoramic telescope (mils)
f. Knob efforts for all sight adjustment knobs (inch-ounces)
g. Accuracy of sight mount level vials
h. Ease of operation of all adjustments
i. Ease of focusing and sighting. Note particularly any evidence of lens fogging.
j. Any damage, misalignment, etc., resulting from the dynamic testing.

4.1.5 <u>Analytical Plan</u>. See paragraph 6.

4.2. <u>Road Tests</u>.

4.2.1 <u>Objective</u>. To determine the ability of the sighting systems to withstand road travel conditions.

4.2.2 <u>Standards</u>. MIL-F-13926, MIL-F-14252.

4.2.3 Method. During the road tests, repeat shop checks at specified intervals to measure loss of boresight, loss of synchronization, misalignments, malfunctioning, or damage to components. Also evaluate adequacy of protective coverings. When possible, conduct the road tests between the direct-fire and indirect-fire phases of testing. The procedure is as follows:

a. Following complete shop checks (para 4.1), prepare the on-carriage fire control components for road testing in accordance with standard procedures (i.e., all sights positively secured on their respective mounts, and protected with approved coverings).

b. After the above preparations are completed, road-test the test vehicle at least 134 km (83 mi) as shown in Table 1.

TABLE 1 - ROAD TESTING SCHEDULE

Course[a]	Speed km/hr (mph)	Approximate Km (Mi)
Washboard, 6-inch	16 (10)	1.6 (1.0)
Paved road	16 (10)	32.2 (20.0)
Washboard, Radial	16 (10)	1.6 (1.0)
Three-Inch Spaced Bump	16 (10)	1.6 (1.0)
Cross-Country Course No.1	16 (10)	32.2 (20.0)
Gravel connecting roads	32 (20)	64.4 (40.0)

[a]See TOP 1-1-011[3] and TOP/ITOP 2-2-506.[4]

c. Following the road testing, check the fire control sights related components again, as specified in para 4.1.

4.2.4 Data Required. Record the following minimum data:

a. Adequacy of protective covers for sighting systems
b. Adequacy of all sight locking devices
c. Any loosening of mounting bolts, set screws, etc.
d. Durability of lighting system for all sights, mounts, etc.
e. Any evidence of interference between components or binding of electric leads
f. After road testing, all shop check data prescribed in para 4.1.

4.2.5 Analytical Plan. See paragraph 6.

4.3 Basic Firing Tests.

4.3.1 Objective. To verify the accuracy, ruggedness, and repeatability of the various sighting system components when they are subjected to firing shocks at normal temperature conditions.

4.3.2 Standards. MIL-F-13926, MIL-F-14252.

4.3.3 Method. Unless otherwise specified, the firing tests consist of the following phases: direct fire at ambient temperature and indirect fire at ambient temperature.

a. Direct Fire. Testing the direct-fire system at ambient temperature consists of firing 5- to 10-round accuracy groups at a vertical target at a range of 1000 to 1500 m and testing in accordance with TOP 3-2-700[5], ITOP's 3-2-605[6] and 4-2-829[7], as appropriate.

b. Indirect Fire. Testing the indirect-fire system at ambient temperature consists of firing at least 75 standard rounds, as shown in (5) below. Check the ability of the system to consistently and accurately lay the major armament by means of transits as shown in Appendix A. Typical results are shown in Appendix C, Table C-1. The method employed to determine the accuracy of the indirect-fire (panoramic) telescope and its mount involves finding the true azimuth of the tube by sighting with a transit along a line scribed on the tube's outer surface. This line lies in the same vertical plane as the tube centerline. If the tube is tapered, however, the azimuth read by the transit will not coincide with the true lay of the tube when the vehicle is canted. The method of computing the tube azimuth correction factor is described in Appendix A.

(1) Before firing, place the weapon on level ground and boresight on a distant aiming point in accordance with established procedures.

(2) After the gun tube is laid on the assigned firing azimuth, locate the aiming posts and transits about the weapon, as shown in Appendix A.

(3) Align the panoramic (indirect-fire) telescope on the proper firing azimuth according to established procedures; center the cross-level vial bubble.

(4) Set the firing elevation into elevation quadrant and elevate the gun until the elevation quadrant level vial bubbles are centered. Center the bubble in the cross-level vial.

(5) Unless otherwise specified, fire at least 75 rounds (i.e., 15 five-round groups), using appropriate ammunition components, in accordance with the schedule shown in Table 2.

TABLE 2 - INDIRECT-FIRE SCHEDULE

Test Group	Test Round No.	Gun Elevation (degrees)	Vehicle Attitude (degrees)	
			Cant	Pitch
I	1-5	Zero	0	0
II	6-10	Intermediate	0	0
III	11-15	Maximum	0	0
IV	16-20	Zero	5-10 Right	0
V	21-25	Intermediate	5-10 Right	0
VI	26-30	Maximum	5-10 Right	0
VII	31-35	Zero	5-10 Left	0
VIII	36-40	Intermediate	5-10 Left	0
IX	41-45	Maximum	5-10 Left	0
X	46-50	Zero	0	5-10 Dep.
XI	51-55	Intermediate	0	5-10 Dep.
XII	56-60	Maximum	0	5-10 Dep.
XIII	61-65	Zero	0	5-10 Elev.
XIV	66-70	Intermediate	0	5-10 Elev.
XV	71-75	Maximum	0	5-10 Elev.

4.4 Climatic Tests.

4.4.1 Objective. To verify the accuracy, ruggedness, and repeatability of the various sighting system components when they are subjected to firing shocks at extreme temperature conditions, and to check the effects of solar radiation, rain, and humidity.

4.4.2 Standards. MIL-STD-810D[13]; MIL-F-13926A[14], MIL-F-14252.[15]

4.4.3 Method. Unless otherwise specified, the climatic tests consist of the following phases: extreme temperature tests at 52° C and -46° C, solar radiation test, night performance at ambient temperature, rain test, and humidity test.

a. Extreme Temperature Tests. When possible, conduct extreme temperature tests of the system concurrently with tests of the major armament. If this is not feasible, conduct these tests after the indirect-fire phase is completed (b above).

(1) At the completion of all shop checks, prepare the weapon for extreme temperature testing in accordance with standard procedures; then place it in a climatic testing facility.

(2) To conduct extreme temperature tests of the entire weapon system, place the weapon in a chamber at ambient temperature. Raise the temperature to 52° C and soak the weapon (i.e., held at temperature) for at least 24 hours. Thermocouples may be used to ensure that the components of interest reach within 1° C (2° F) of the prescribed temperature. Following firing tests ((3) below) set the chamber at -46° C, and once the chamber reaches the prescribed temperature, soak the weapon for at least 24 hours or until the components of interest reach within 1° C of the prescribed temperature.

NOTE: The above temperatures assume a requirement to meet the hot-dry and cold climates of AR 70-38.[b] Other temperatures will be used if so prescribed.

(3) At each temperature level (after soaking), fire at least 10 standard rounds in accordance with Table 3. Immediately before and immediately after firing each temperature phase, conduct the following inspections and checks of all on-carriage fire control components:

(a) Knob efforts of all adjustments
(b) Ease of operation
(c) Evidence of fogging of optics
(d) Clearness of reticles
(e) Adequacy and dependability of illumination for dials, vials, counter windows, reticles, etc.

(f) Flexibility and effectiveness of eyepiece rubber guards, etc.

(g) Evidence of any failure of optical sights (i.e., failure of bonding cements for prisms, inability to focus sights, etc.)

(h) Misalignment, damage, or abnormal play between sights and their mounting surfaces.

(i) Any failure of leveling vials (i.e., loss of bubble, glass fracture, etc.).

(j) Ease of installing and removing sight protective covers; particular attention should be paid to the pliability of the material (i.e., canvas, plastic, rubber, etc.) at low temperatures.

(4) Following completion of the above testing, return the weapon to the shop for recheck of all fire control components as specified in paragraph 4.1.

TABLE 3 - EXTREME TEMPERATURE FIRING

Test Phase	Soaking Temperature °C	Soaking Temperature °F	Test Round No.	Gun Elevation
I	52	+125	1-5	Minimum
	52	+125	6-10	Maximum
II	-46	-50	11-15	Minimum
	-46	-50	16-20	Maximum

NOTES: 1. Fire control checks are made at the following intervals:

(a) Before firing 52° C
(b) After firing round 10
(c) Before firing round 11
(d) After firing round 20

2. Record recoil cycle times and recoil lengths for all rounds.

3. Minimum and maximum gun elevations are normally restricted by the limitations of the climatic testing facility.

4. After emplacement in the climatic facility, all standard maintenance procedures should be completed before soaking the weapon at extreme temperatures.

b. Solar Radiation Test. Because the sights are in an exposed position and because of their relatively low heat capacity, they will reach much higher temperatures under the desert sun than will the heavier portions of the weapon system. Conduct the solar radiation test of optical sights to determine whether the high temperatures will damage the seals, adhesives, optical alignment, or other portions of the sights.

(1) Align the sight and the barrel on a distant target. Remove and expose the sight to a solar radiation test in accordance with ITOP 4-2-826.[8]

(2) After exposure, examine the sight for damage and reassemble to the weapon. Note difficulties in aligning on a distant target. Ascertain damage from firing shock.

NOTE: If the developer has conducted sufficient solar radiation tests, the TECOM test agency should include the data in the test report and should eliminate this test.

c. Night Performance. Following the extreme temperature firings (and solar radiation firing, if applicable) and shop checks, conduct the night performance test to determine the effects of muzzle flash and smoke. Before the test, check night performance data pertaining to illumination, functioning, and clarity of objects (target) in accordance with TOP 2-2-616.[9] Conduct testing in as complete darkness as possible to permit a full evaluation of the dial and reticle illumination systems.

(1) Before and immediately after firing, perform functional checks on all illumination and sighting system controls and adjustments.

(2) Place the weapon on level ground, boresight it, and establish a target aiming point.

(3) Fire the weapon with 5 to 10 standard rounds at an illuminated target 1000 m down range.

d. Rain Test. Conduct a rain test in accordance with TOP 2-2-815.[10] It may be necessary, in the case of some blowing rain facilities, to remove the sight from the weapon to expose it properly. Following exposure to 31.3 cm (12-1/3 in.) of rain, examine the sight for evidence of water and moisture penetration and ease of operation. It is not necessary to fire the weapon to check the sight.

e. Humidity Test. Conduct a 240-hour humidity cycling test in accordance with ITOP 4-2-820.[11] As in the case of the rain test, it may be desirable to remove the sight from the weapon before placing it in the chamber. Following exposure, examine the sight for corrosion, condensation, penetration of moisture, and expansion. Check the operation of the sight as well. There is usually no need to recheck the sight for ability to withstand weapon firing.

5. DATA REQUIRED.

5.1 Direct Fire. NOTE: Record the data indicated in a through f below immediately before and after firing each round.

a. Breech ring elevation, as measured with a calibrated gunner's quadrant

b. Direct-fire telescope mount elevation, as measured with a calibrated gunner's quadrant

c. Tube azimuth, as measured by transit

d. Counter-elevation readings of the elevation quadrant

e. Azimuth reading of the panoramic telescope

f. Cant of trunnions

g. Horizontal and vertical displacement of the direct-fire telescope crosshairs with respect to the target aiming point, as measured after firing

h. Coordinates of projectile impacts on vertical target

i. Muzzle velocities of all projectiles

j. Projectile weights to nearest 0.004 kg (0.01 lb)

k. Shift in boresight for each round

l. Chamber pressure for each round

m. Surface wind direction and velocity

n. Complete nomenclature of weapon, sighting system, and ammunition components

o. Ease of operation and adequacy of the direct-fire telescope and mount

p. Ability of the sighting system to withstand firing shocks

q. After firing, complete shop check data as specified in paragraph 4.1.4.

5.2 Indirect Fire. Record the following data before and immediately after firing each five-round group listed in Table 2 (para 4.3.3b(5)). After completion of all phases of firing, record complete shop check data as specified in paragraph 4.1.4.

a. Counter elevation, as measured by the elevation quadrant

b. True tube elevation, as measured by placing a calibrated gunner's quadrant on the breech ring

c. Tube azimuth, as measured on azimuth counter (scale) of the panoramic telescope

d. True tube azimuth, as measured by transits (App. A)

NOTE: Azimuth read by transit must be corrected for tube taper and vehicle cant, as shown in Appendix B.

e. Cant of trunnions; as measured by a calibrated gunner's quadrant placed on appropriate breech ring pads, cant correction device, or special

L-bar attached to trunnions. Also, leveling bar placed on bull ring of self-propelled vehicles is used to determine vehicle pitch and cant (see para 3, Fig. 1).

f. Sight azimuth, as read on deflection scale of indirect-fire system
g. Shift in boresight
h. Displacement of aiming posts, as recorded by panoramic telescope
i. Wind direction and velocity; temperature
j. Ease of operation and adequacy of the indirect-fire telescope, mount, and related elevation quadrant
k. Ability of the sighting system to withstand firing shocks

5.3 Extreme Temperature and Solar Radiation Tests. Record the following minimum data before and after firing at each temperature level (i.e., 52° C and -46° C) and before and after the solar radiation test. After the tests, record the shop check data specified in paragraph 4.1.4.

a. Knob efforts of all adjustments of the sighting systems
b. Ease of operation, especially when wearing arctic gloves at -46° C
c. Fogging of optics
d. Adequacy and dependability of the illumination for dials, reticles, counters, etc.
e. Distortion of field of view of telescopes due to failure of optic components (bonding cement, set screws, etc.)
f. Pliability and general acceptability of rubber eye guards
g. Pliability and acceptability of protective sight covers
h. Ease of installing and removing sights
i. Positive security of sights on their respective mounts
j. Any evidence of damage, misalignment, etc, as a result of firing
k. Firing record data (i.e., weapon and ammunition identification, peak chamber pressures (copper crusher gauge) on typical rounds)

5.4 Night Performance. Record the following minimum data before and after firing.

a. Adequacy and dependability of illumination for dials, reticles, counters, etc.
b. Objectionable reflection of light from sighting systems that would permit easy detection under combat conditions
c. Adequacy of focusing, field of view, etc.
d. Ability to see illuminated target clearly
e. Any interference or obstructions in the line of sight
f. Effects of muzzle flash on time required for gunner to see target clearly

6. PRESENTATION OF DATA.

a. Present all test data in such a manner that the overall accuracy, ruggedness, ease of operation, and adequacy of the sighting systems can be evaluated readily and compared with the pertinent specification or design requirements.

b. When applicable, prepare a "Transit Azimuth Correction versus Elevation" chart (App. B, Fig. B-5).

c. Tabulate round-by-round data, and prepare a chart showing actual round impacts on a vertical target (direct-fire phase) (b(2) below and App. C).

d. Include photographs of mounted and unmounted sights as part of the formal report, along with a general description of the major components. In this description, particular emphasis should be given to any uniqueness of design.

e. When practical, photograph and include all failures, misalignments, interference, etc., as part of the formal report. Submit Test Incident Reports (STE Form 1025) as required. The final report will contain a summation of all deficiencies, shortcomings, etc.

f. When specified, present range firing data as indicated in the appropriate document (i.e., TOP 3-2-700, MTP 3-1-004[12], and ITOP 4-2-829).

6.1 System Errors versus Sight Errors.

a. Generally speaking, the errors in a field artillery fire control sighting system can be categorized as follows:

(1) Mechanical Errors - Excessive backlash or play, poor workmanship, deformed parts (i.e., gears, linkages, etc.)

(2) Optical Errors - Errors attributed to poor quality prisms, lenses, or other optical components; defective components (e.g., reticles); or poor assembly procedures (i.e., nonparallel mounting planes which permit angular deviations of optical centers or sight lines)

(3) Mechanical-Optical Errors - Combinations of 6a and b above. A poorly fitted prism holder, for example, would be classified in some cases as errors in both systems.

(4) Unexplainable Errors - Those errors which cannot be charged to the three above. For example: human errors; also, errors resulting from firing at vertical targets (such as variations in interior and exterior ballistics, faulty meteorological data, unknown projectile yaw, changes in muzzle velocities, etc.). It must be remembered, however, that any firings for accuracy or precision (TOP 4-2-829) involve all gun-ammunition-human components; not just the errors of the sighting system as herein discussed.

b. After all testing is completed, data are usually presented in tabular form as shown in Appendix C. Round-to-round dispersion is presented also in graphic form (App. C, Fig. C-7). Probable errors (PE) or standard deviation (σ) are usually calculated by the root-mean-square method. Centers of impacts (App. C, Fig. C-7) are plotted for each 5-to 10-round group (not including warmer rounds).

c. In the majority of cases, the mechanical and optical errors can be separated by an analysis of the data obtained. It is assumed that all components of the sighting system meet specification tolerances before their receipt by a development test agency which always should have available master telescopes, etc., that are periodically checked by the responsible fire control office.

d. An example of the separation of "component" from "system" errors is as follows (from report DPS-1020): At the conclusion of all testing, it was found that the T177 panoramic telescope reticle moved in elevation about 1 mil when the azimuth knob was operated. Also, the T206 direct-fire mount would not allow proper installation of the T176E2 direct-fire telescope. The mount (T206) was returned to the Frankford Arsenal laboratories where it was found that there was a misalignment of 35 minutes of arc between kingpin holes. Further examples are given in the above report.

APPENDIX A

TYPICAL PROCEDURE FOR DETERMINING AZIMUTH ERROR OF INDIRECT-FIRE SIGHTING SYSTEM (M109 SELF-PROPELLED VEHICLE SHOWN)

Step I. Boresight the howitzer tube and indirect-fire telscope on a distant target or aiming point (i.e., 2000 m range approximately). Set the azimuth counter of the sight (M117) to 3200 mils. (If not 3200 mils, error must be compensated in computations, which follow.) This should be done with sight bubbles level and vehicle on level terrain to minimize inherent errors.

II. With the vehicle on sloped terrain (to induce cant), elevate the howitzer to the desired counter (H_c) reading of the elevation quadrant (M15). The sight bubbles must be kept cross-leveled.

III. Measure the quadrant elevation (H_q) with a calibrated gunner's quadrant placed on the breech ring quadrant pads. Care must be taken to ensure positive measurement of the vertical angle. This is accomplished by rocking the quadrant from side to side, using the aligned edges of its shoes as the pivoting axis, and adjusting the micrometer until the quadrant level bubble has established the true horizontal plane.

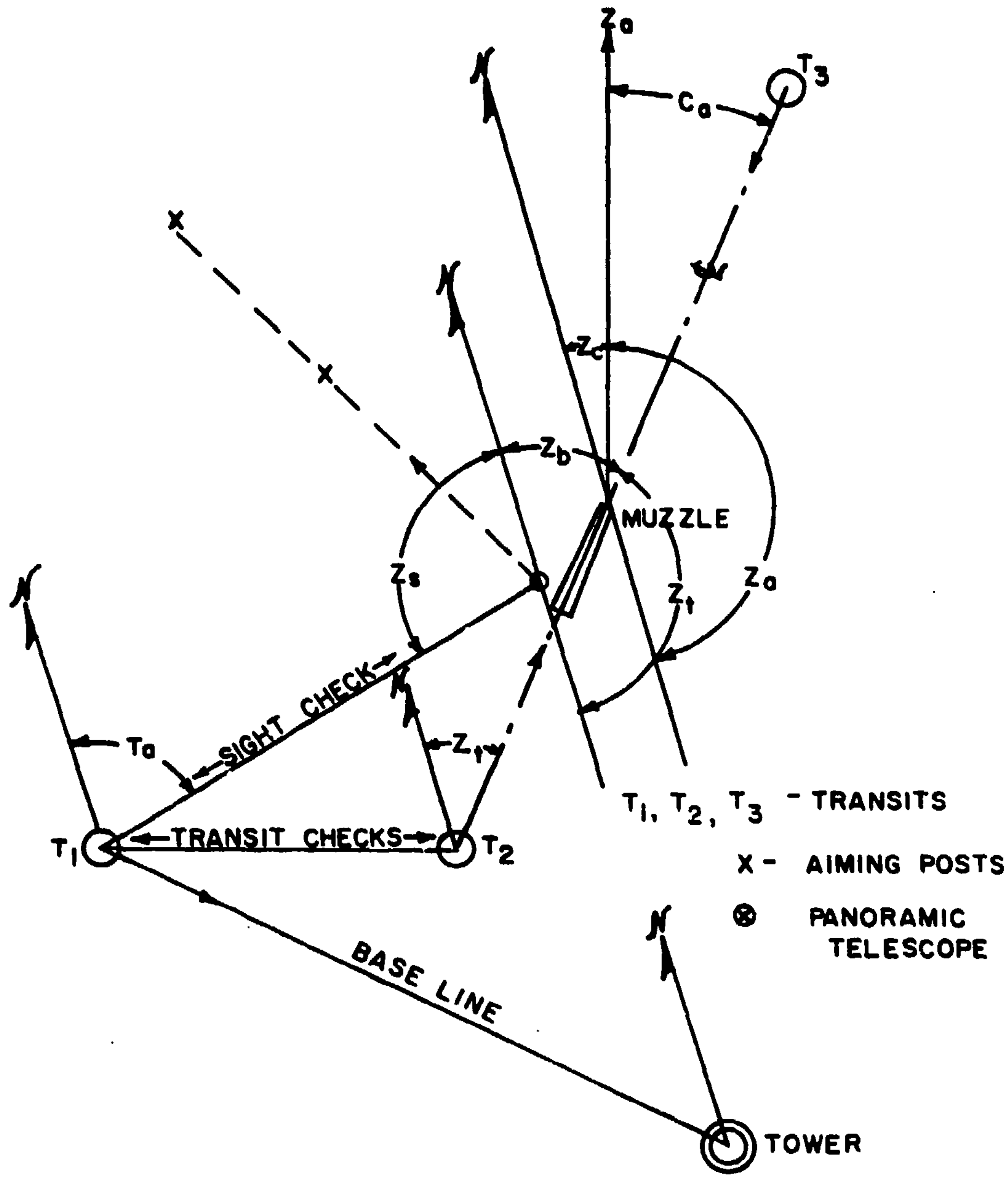
IV. Locate a surveyor's transit (T_1), whose angular position can be established on the vehicle flank (Fig. A-1). Use the transit telescope as a fixed aiming post.

V. By transit (T_1), measure the true azimuth T_a) of the extended centerline of the vehicle sight with reference to an orientation check point (e.g., tower, fig. 4).

VI. Next, compute the true azimuth (Z_s) of the aiming sight line as follows: $Z_s = T_a - 180°$; Example: $Z_s = 307°00'35''$; $Z_s = 307°00'35'' - 180° = 127°00'35''$.

VII. Subtract the assigned firing azimuth (Z_a) from the true azimuth (Z_s) of the aiming sight line if right traverse is desired, as shown in the following example: Z_s = 2268 mils, Z_a = 711 mils; hence $Z_s - Z_a$ = 1557 mils. This number is then set into the counter of the Panoramic Telescope M117. This operation will move the aiming sight line off the target (T_1) to the left.

VIII. Traverse the weapon to the right to realign the sight with target (T_1), making certain to always lay the weapon in the same direction. This may require two or more trials to determine the precise setting of all adjustments, including those of the elevating and traversing handwheels of the vehicle. Recheck the elevation quadrant counter (H_c) and sight bubbles to ensure that the original settings have not changed.



NOTES:
1. This is a theoretical problem.
2. Angular errors are purposely magnified for clarity.
3. Transit (T3) azimuth must be corrected for tube taper.
4. C_a seldom exceeds 10 mils.

Figure A-1. Determination of Cant Correction Error (C_a) in Azimuth.

IX. Measure the resulting true azimuth (Z_t) with a second transit (T_2) after aligning a series of scribed lines (previously established on level terrain) on the top or bottom side of the howitzer tube to indicate the bore axis, using the orientation point (tower) and the transit (T_1) to establish the true azimuth (Z_t).

NOTE: If transit T_3 is used, the correction for taper is the reverse of that used for T_2 readings.

X. Cant correction error of azimuth (C_a) is the angular difference between Z_t and Z_a; i.e., $C_a = Z_a - Z_t$; Example: $C_a = 711.1 - 709.8 = 1.3$ mils. It is called plus (+) if Z_t is greater and minus (-) if Z_t is less than Z_a.

XI. If the vehicle is canted and if the tube is tapered so that the scribe lines mentioned in Step IX above are located at different tube diameters, the azimuth read by the transit (T_2) will not coincide with the azimuth (Z_t) of the tube. The transit reading must therfore be corrected before it can be compared with the azimuth indicated by the fire control system. This correction is called the transit error (T) and is computed in accordance with the following equation.

$$\text{Tan } T = \frac{\text{Sin } K}{\frac{L \cos^2 E}{R - r} - \text{Sin } E \, (\cos^2 E - \sin^2 K)}$$

in which:
K = Angle of cant
E = Tube elevation in respect to horizontal plane
L = Length between scribe lines
R = Radius of tube at scribe line near trunnion
r = Radius of tube at scribe line near muzzle
T = Transit error

NOTE: The derivation of this formula is given in Appendix B.

XII. The cant correction error of elevation (C_e) is the angular difference between the howitzer elevation (H_q) and the elevation quadrant setting (H_c). It is called plus (+) when H_c is greater and minus (-) if H_c is less than H_q. This error (C_e) is always checked to make sure it has not adversely affected the azimuth errors.

XIII. With the howitzer still positioned on its assigned line of fire (Z_a), set aiming stakes at a deflection of 2600 mils with the panoramic telescope. Place the far stake 91.4 m (100 yd) from the vehicle and the second stake at the midpoint directly in front of the far stake. Due to the short distance to the aiming posts, slight movements of the panoramic telescope from shock of firing or from cab traverse will move the line of sight off the aiming posts. This deviation is called displacement, and the procedure for correcting for displacement or recording is contained in FM 6-81[e] concerning service of the weapon.

APPENDIX B

A METHOD FOR TESTING THE ACCURACY OF THE CANT CORRECTOR IN A FIRE CONTROL SYSTEM*

1. INTRODUCTION.

A general method for determining the accuracy of a cant corrector in a fire control system involves comparing the azimuth of the gun tube as read from the fire control system with the azimuth obtained by a transit. The method is illustrated below application to the 155-mm howitzer, self-propelled, M109, with tube M185.

2. PROCEDURE.

To test the accuracy of the cant corrector in a fire control system, a line is scribed on the outside surface of the gun tube. When the trunnion is in a horizontal plane, this line is a segment of the line in which the vertical plane containing the axis of the tube intersects the lower outside surface of the tube. The azimuth of this scribed line, for a given weapon setting, can be determined with a transit in front of the gun. The azimuth of the scribed line is not the true azimuth of the gun tube, however, if the weapon is canted and the tube is tapered. When the mount is canted and the outside of the tube is tapered, the scribed line is in a different vertical plane from the axis of the tube. The size of the smaller dihedral angle formed by these two vertical planes is the amount by which the scribed-line azimuth differs from the azimuth of the bore. The size of this dihedral angle depends upon the taper of the tube, the cant of the weapon, and the elevation of the tube. For a given tube with known taper, the size of this dihedral angle can be determined for various combinations of cant and elevation. The scribed-line azimuth, as read from the transit, can be changed accordingly to give the azimuth of the tube.

Using the fire control system, the tube can be traversed to an assigned firing azimuth and elevation. The azimuth of the scribed line can be determined with the transit, corrected for effects due to the taper of the tube, and then compared with the reading from the fire control system.

If this routine is performed for various tube elevations at various right and eft cants, accuracy of the cant corrector can be evaluated.

3. DERIVATION OF FORMULA FOR MAKING CORRECTIONS.

In Figure B-1, the line O-N is the intersection of the horizontal plane and the vertical plane containing the axis of the tube and is, therefore, the true azimuth of the tube. The line O-M is the intersection of the horizontal plane and the vertical plane containing the scribed line and is the azimuth given by the transit.

Angle T, the plane angle of the dihedral angle formed by the two vertical planes, is the difference between the azimuth of the tube and the azimuth of the scribed line.

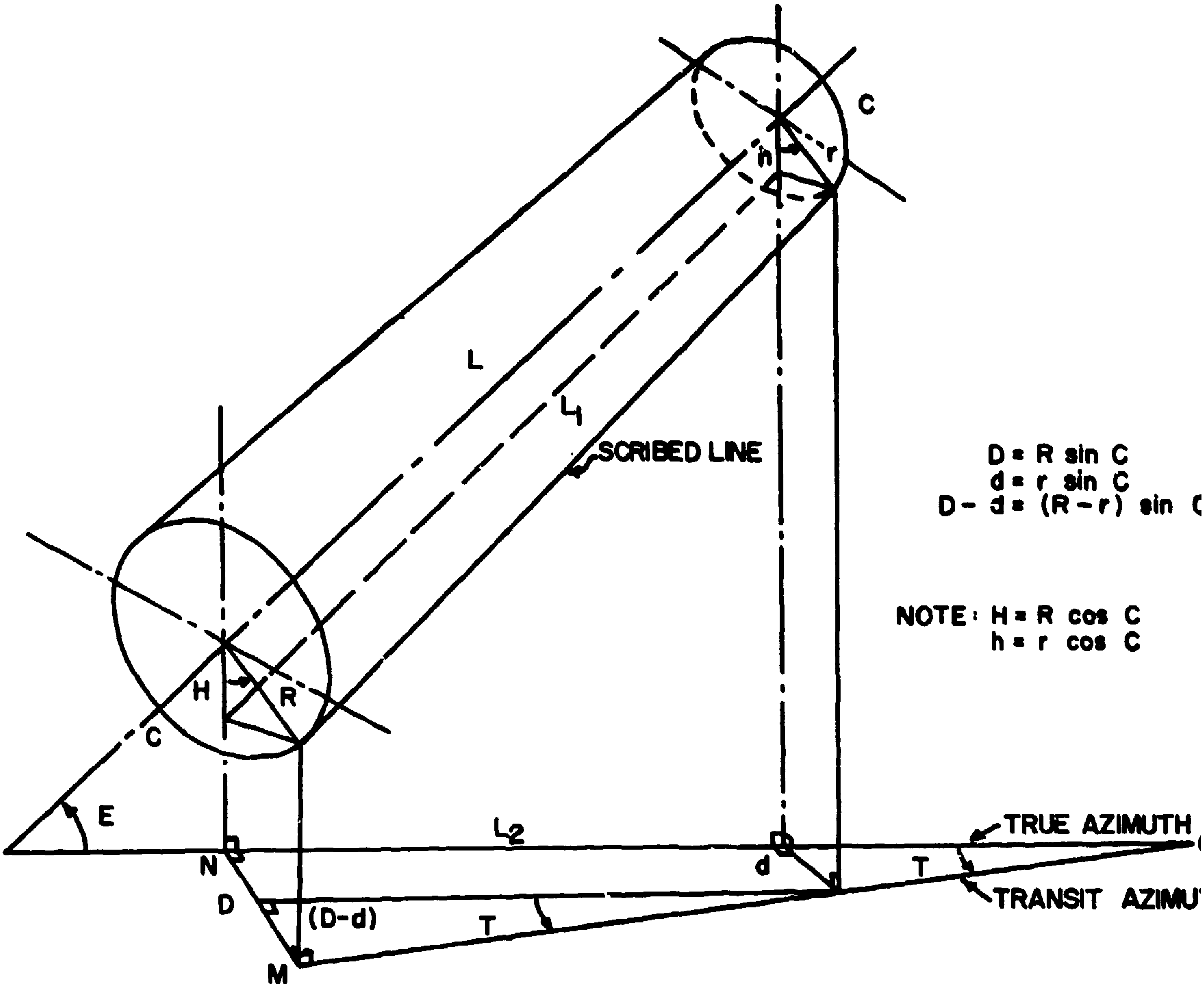


Figure B-1. Derivation of Transit Correction Angle (T).

In Figure B-1: $$\tan T = \frac{D - d}{L_2} \quad (1)$$

and $$D - d = (R - r) \sin C$$

therefore $$\tan T = \frac{(R - r) \sin C}{L_2} \quad (2)$$

in which: R and r are radii of the tube at the extremities of the scribed line.

C = the plane angle of the dihedral angle formed by the vertical plane containing the axis of the tube and the plane in which the tube is actually elevated.

From Figure B-2: $L_2 = \quad - p + P$ (3)

$L_2 = L \cos E - R \cos C \sin E + r \cos C \sin E$ (4)

$L_2 = L \cos E - (R - r) \cos C \sin E$ (5)

in which: E = the angle of elevation of the tube with respect to the horizontal firing plane (Angle E is measured in the vertical plane of the axis of the tube.).

L = the length of the orthogonal projection of the scribed line on the axis of the tube.

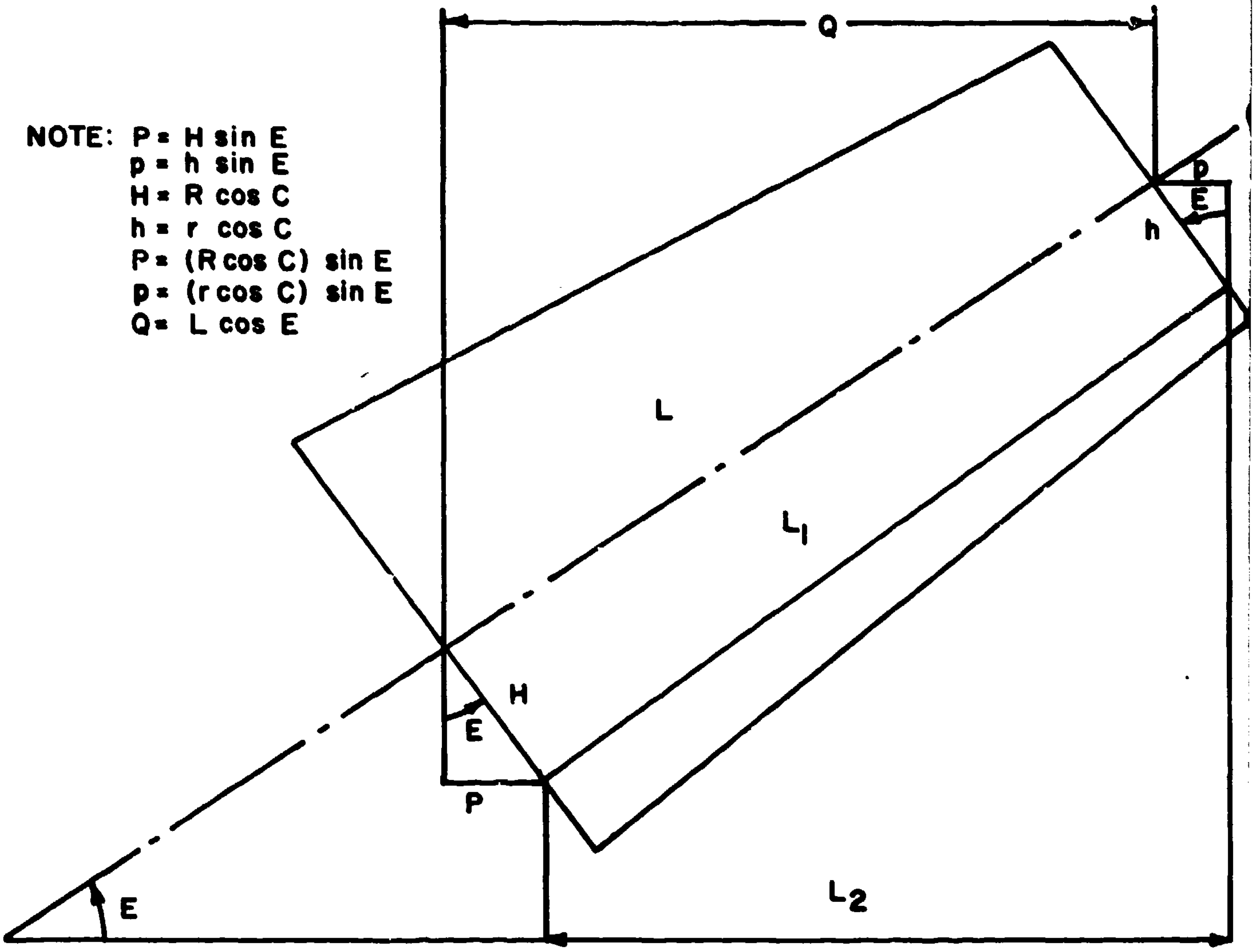


Figure B-2. Side View of Tube.

Let K be the angle of cant, i.e., the measure of the dihedral angle formed by the plane of the trunnion and the horizontal plane through the axis of the trunnion. Using the diagram in Figure B-3, it can be shown that:

$$\text{Cos } A = \cos a \times \sin C \tag{6}$$

$$\text{Sin } C = \frac{\sin K}{\cos E} \tag{7}$$

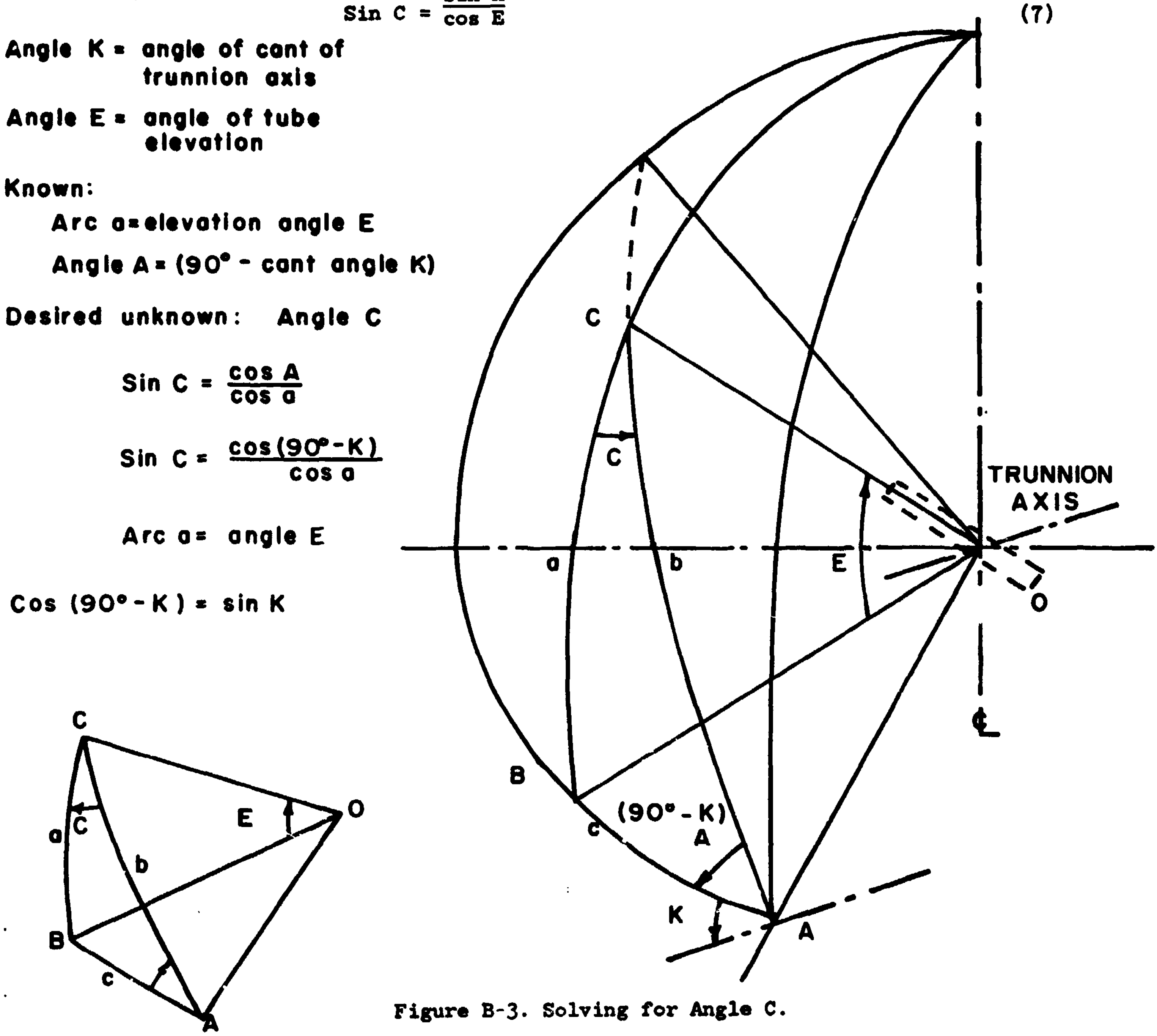


Figure B-3. Solving for Angle C.

Substituting equations (5) and (7) in equation (2) gives:

$$\tan T = \frac{\dfrac{(R - r)\sin K}{\cos E}}{L \cos E - (R - r)\cos C \sin E}$$

Replacing cos C in equation (8) by the equivalent form $(1 - \sin_2 C)_{1/2}$ and simplifying the resulting equation gives:

$$\tan T = \frac{\sin K}{\dfrac{L \cos^2 E}{R - r} - \sin E\,(\cos^2 E - \sin^2 K)^{1/2}} \quad (9)$$

Using equation (9), T can be determined from functions of known angles.

4. RESULTS.

Formula (9) was used to determine the corrections that must be applied to the scribed line azimuth, as read from the transit, to give the true azimuth of the tube. The corrections, plotted in the graph (Fig. B-5), apply to the 155-mm Howitzer, SP, M109 with Tube M185 when the scribed line is on the portion of the tube indicated in Figure B-4. To obtain the corrections the following data were used:

Length of scribed line = 13.81 in.
Outside diameter of the tube at one end of the scribed line = 11.069 in.
Outside tube diameter at the other end of the scribed line = 9.79 in.
L = 13.80 (L = 13.80 cos where = arc sin 0.638/13.81)

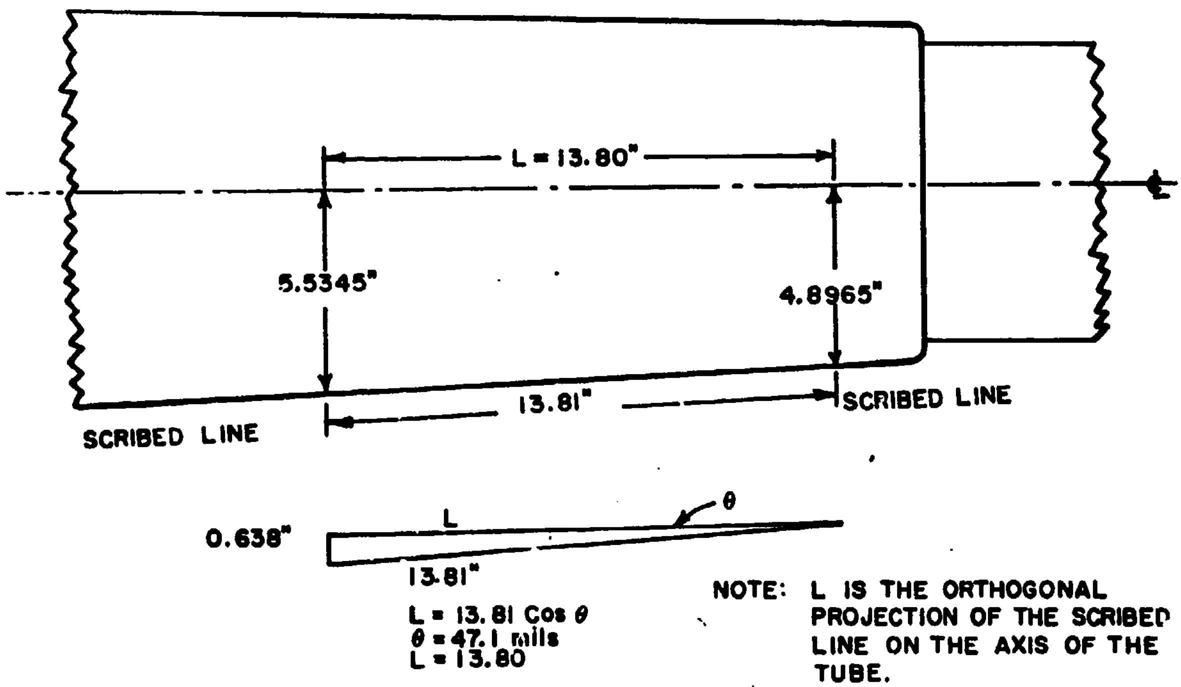


Figure B-4. Section of Jacket, 155-mm Howitzer Tube M185.

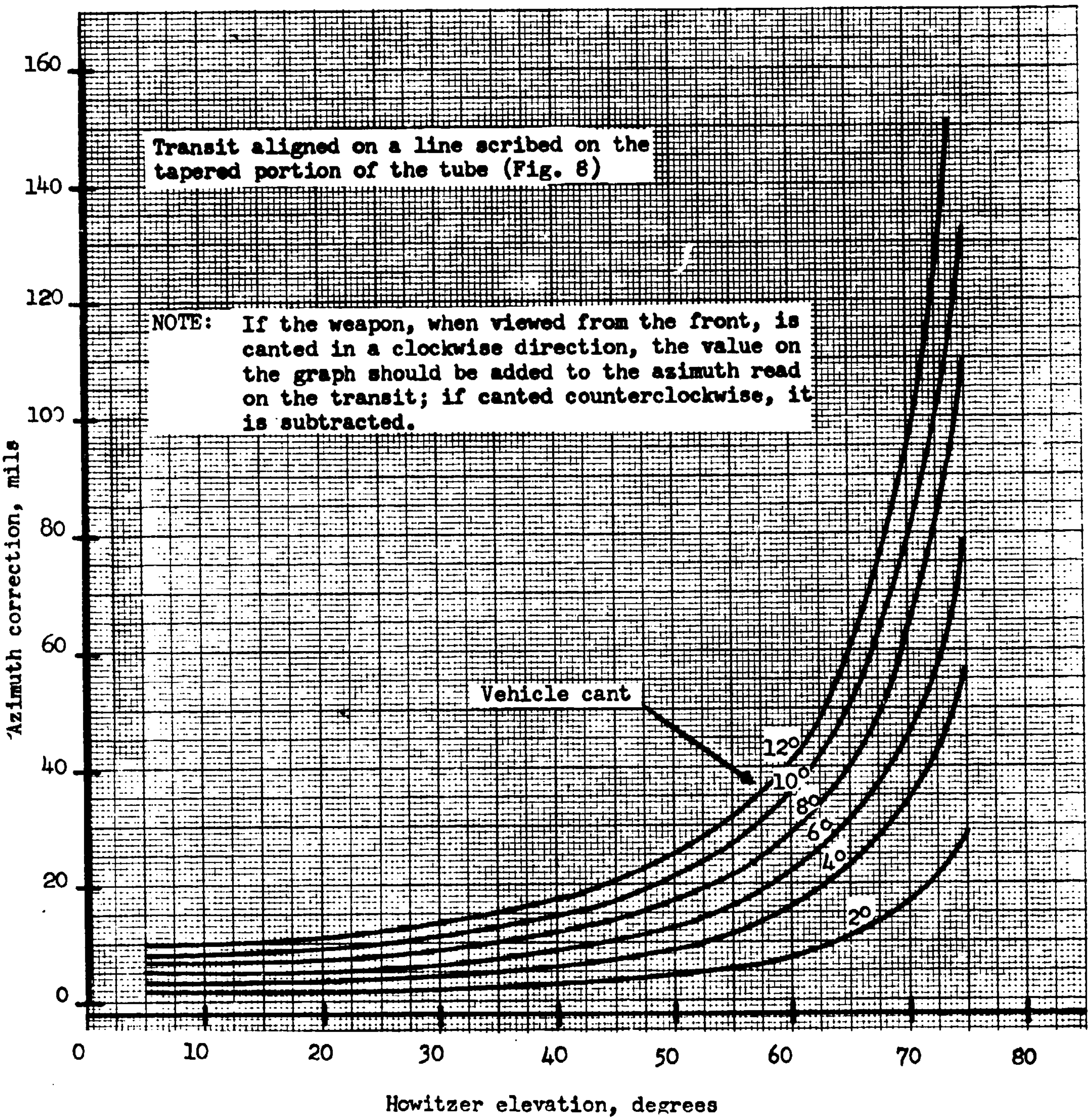


Figure B-5. Transit azimuth correction vs howitzer elevation, 155-mm howitzer, SP M109, M185 tube.

APPENDIX C

TYPICAL TEST RESULTS

Actual fire control check data obtained for the T196E1 (155-mm Howitzer, Self-Propelled) during an initial production test are shown in Tables C-1 through C-9 and Figure C-1. All fire control tests were conducted inside of a building.

TABLE C-1 - BORESIGHT RETENTION (DIRECT FIRE), 155-MM HSP M109

When Taken	Boresight Reading (mils)		Boresight Change (mils)	
	Elevation	Azimuth	Elevation	Azimuth
Before Firing	4.0	4.0		
Completion of Tests	3.9	4.3	-0.1	+0.3

NOTES:

1. Boresight retention checks were made on a 1,500-yard (1,371.60-m) aiming point.

2. Change in:

   Elevation = 4.0 - 3.9 = -0.1 mil
   Azimuth = 4.3 - 4.0 = +0.3 mil

3. Specification allows ± 0.5 mil. Boresight retention errors are well within allowable tolerances.

TABLE C-2 - BORESIGHT RETENTION (PANORAMIC TELESCOPE)

When Checked	Boresight Reading (mils)	
	Panoramic Telescope OEM	Panoramic Telescope Master Control*
Before Firing	3,200.0	0.0
After Firing 285 Rounds	3,201.0	1.5
After Firing 416 Rounds	3,200.8	1.3

*Master control telescope, same model as that supplied with OEM. This scope was previously checked at Frankford Arsenal for accuracy.

TABLE C-3 - SYNCHRONIZATION (ELEVATION/DEPRESSION) - MILS (INDIRECT FIRE)

Direction of Movement	M15 Quadrant Setting		M15 Quadrant Seat		Breech Ring Elevation		Panoramic Telescope Counter Reading		Panoramic Telescope Mount Quadrant Seat	
	B.F.	A.F.	B.F.	A.F.	B.F.	A.F.	B.F.	A.F.	B.F.	A.F.
E	0.0	0.0	+0.1	+0.4	+0.3	+0.5	+0.4	+22.5	+0.3	+22.5
	100.0	100.0	100.0	100.0	99.9	99.8	100.3	122.2	100.3	122.3
	500.0	500.0	500.0	500.0	500.0	500.1	500.75	522.5	500.3	522.8
	600.0	600.0	600.0	600.0	599.5	600.1	600.5	622.5	600.8	623.1
	1,000.0	1,000.0	1,000.0	1,000.0	999.6	999.5	1,000.6	1,022.5	1,000.8	1,022.1
	1,300.0	1,300.0	1,300.0	1,300.0	1,299.5	1,299.6	1,300.4	1,322.5	1,300.5	1,322.7
	1,311.5	1,315.5	1,311.5	1,315.5	1,311.3	1,315.4	1,312.0	1,337.5	1,313.6	1,338.1
D	1,300.0	1,300.0	1,300.1	1,300.0	1,300.0	1,299.6	1,300.0	1,321.9	1,300.1	1,322.8
	1,000.0	1,000.0	1,000.0	1,000.0	999.6	999.6	1,000.1	1,022.9	1,001.1	1,022.9
	600.0	600.0	600.0	600.0	600.2	599.9	601.1	623.0	601.6	623.4
	500.0	500.0	500.0	500.0	500.1	500.0	501.0	522.0	501.3	523.1
	0.0	0.0	0.0	0.0	+0.5	-0.1	+0.4	+21.0	0.0	21.9
	-53.5	-49.0	-53.5	-49.0	-52.7	-49.3	-52.7	-28.0	-	-

E = Elevating
D = Depressing
B.F. = Before firing
A.F. = After firing

Remarks: Elevation readings at seats (pads) were taken with a calibrated Gunner's Quadrant M1. Backlash averaged 0.65 mil.

TABLE C-4 - WALKOFF DATA (PANORAMIC TELESCOPE) - MILS

Elevation (Breech)	Walkoff		
	Specified	Before Firing	After Firing
0 to 800	---	---	0.5
0 to 1,100	0.5	0.8	1.0
0 to 1,300	---	2.0	1.9

TABLE C-5 - SHAKE READINGS - MILS

Elevation (Breech)	Deflection		
	Specified	Before Firing	After Firing
0	0.3	0.1	0.3
800	---	1.0	1.5
1,100	1.5	2.1	3.1
1,300	---	4.8	5.8

TABLE C-7 - ADJUSTMENT KNOB TORQUES (IN.-LB)

Knob	Ambient Temperature				-40° F		-65° F	
	Before Firing		After Firing		Before Firing		Before Firing	
	CCW	CW	CCW	CW	CCW	CW	CCW	CW
Indirect Fire Telescope:								
Pitch	10	6	6	4	15	12	35	25
Cant	6	5	5	5	5	5	5	5
Azimuth	4	3	5	5	8	6	10	10
Elevation Control	5	6	3	5	7	8	10	12
Elevation Correction	4	3	3	2	3	5	3	4
M15 Quadrant:								
Cant	5	5	3	4	4	4	12	10
Pitch	9	6	10	7	11	11	35	30
correction	4	4	5	5	5	4	4	4

Remarks: During low temperature firings there was no significant difference between before-firing and after-firing torques.

TABLE C-8 - BACKLASH (PANORAMIC TELESCOPE)

Azimuth Setting (mils)	Deflection of Reticle (mils)	
	Before Firing	After Firing
3,200	0.15	0.15
1,600	0.20	0.25
0	0.30	0.25
4,800	0.20	0.30

APPENDIX D

GLOSSARY

1. Cant: Sidewise tilting of a gun, measured in mils left or right.

2. Ca - Cant Correction Error (Azimuth): The angular difference between the "assigned firing azimuth" (Z_a) and the "true azimuth" Z_t of the howitzer tube. It is called plus (+) if Z_t is greater and minus (-) if Z_t is less than Z_a.

3. Ce - Cant Correction Error (Elevation): The angular difference between the indicated "counter elevation " (H_c) and the true "quadrant elevation" (H_q). It is called plus (+) when Hc is greater, and minus (-) when H_c is less than H_q.

4. Hc - Counter Elevation: The elevation angle indicated by the counter elevation scale.

5. Hq - Quadrant Elevation: The true elevation of the tube as measured by a calibrated gunner's quadrant.

6. Ta - Transit Azimuth of Sight Line: The true azimuth of the extended axis of the sight as measured by a surveyor's transit (T_1).

7. Za - Assigned Firing Azimuth: The azimuth selected for the laying of the weapon.

8. Zb - Supplement of the True Azimuth: The "true azimuth" (Z_t) subtracted from 180°.

9. Zc - Supplement of the Firing Azimuth: The "assigned firing azimuth" subtracted from 180°.

10. Z. - True Sight Azimuth: The true azimuth of "aiming sight line" as measured from the vehicle.

11. Zt - True Azimuth: The firing azimuth as observed by the transit (corrected f - tube taper and vehicle cant).

APPENDIX E

REQUIRED REFERENCES

1. Test Operations Procedure (TOP) 3-2-800, Schedules and Procedures for Inspections and Measurements of Cannon, 17 September 1982, and Change 1, 19 July 1983.

2. TOP 1-2-504, Physical Characteristics, 31 October 1972.

3. TOP 1-1-011, Vehicle Test Facilities at Aberdeen Proving Ground, 6 July 1981.

4a. TOP 2-2-506, Endurance Testing of Tracked and Wheeled Vehicles, 26 June 1981.

4b. ITOP 2-2-506, Endurance Testing of Tracked Vehicles, 15 May 1987.

5. TOP 3-2-700, Ballistic Correction Systems, 8 March 1978.

6. ITOP 3-2-605, Accuracy Firing of Tank Weapons, 7 March 1985.

7. ITOP 4-2-829, Vertical Target Accuracy and Dispersion, 13 December 1985.

8. ITOP 4-2-826, Solar Radiation Tests, 21 September 1983.

9. TOP 2-2-616, Night Performance of Combat Vehicles, 8 May 1981.

10. TOP 2-2-815, Rain and Freezing Rain, 19 June 1975.

11. ITOP 4-2-820, Humidity Tests, 13 January 1984.

12. Materiel Test Procedure (MTP) 3-1-004, Artillery Range and Ballistic Match Firings, 30 June 1970.

13. MIL-STD-810D, Environmental Test Methods, 19 July 1983.

14. MIL-F-13926A, "Fire Control Material, General Specification Governing the Manufacture and Inspection Of", 1 June 1974.

15. MIL-F-14252, "Fire Control Material, General Specification Governing the Design and Inspection Of", 24 February 1959.

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a. ITOP 3-2-604, Boresight Retention, 14 October 1983.

b. AR 70-38, Test and Evaluation of Materiel for Extreme Climatic Conditions, 1 August 1979.

c. TM 9-258, "Elementary Optics and Application to Fire Control Instruments", 5 December 1977.

d. TM 9-3305, "Principles of Fire Control Materiel", 4 May 1981.

e. FM 6-81, "155-mm Howitzer M114, Towed", 28 March 1962.

f. FCDD-282, "Fire Control Equipment for New Family of Field Artillery (Towed)."

g. FCDD-341, "Fire Control Equipment for Self-Propelled Artillery Weapons, T235, T236, and T245."